A New Approach to Image Fixing Quality Assessment - a Pen Offset Apparatus and Image Processing Analyzer

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Abstract

The fixing quality of printed images has conventionally been characterized by the adhesion strength between the image and the substrate, and by the cohesion strength within the image layer. In general, techniques such as the simple Scotch tape test and the crockmeter test have been used to evaluate adhesion and cohesion strength respectively. These two test methods are convenient and easy but they can be unreliable due to large variations in the force applied during the tests; the areas selected for optical density measurements can also influence the results.

The pen-offset method has also been used to assess fixing quality. In this technique, a print is placed face down on a piece of blank paper, and a pen used to write on the back of the image. The fixing quality is judged by visually inspecting the offset image on the blank paper. The test result depends strongly on the force applied and on the evaluator's experience.

The authors have recognized the benefits of the pen-offset method and have developed an apparatus which can apply a constant pressure while writing on the back of the image. An image-processing module has also been developed and compiled into open source code software to evaluate the pen-offset image. The method produces quantitative, reliable and reproducible results.

This paper will introduce the new pen-offset apparatus and the methodology for image analysis using a newly developed image processing software.

Introduction

Fixing of images to substrates is a critical step in any known printing process. In electrophotography, it is usually achieved using a hot-roll contact fusing device or non-contact radiant heating, such as infra-red or flash fusing. The fix quality of printed images is determined by the adhesive and cohesive properties of both the ink layer and the substrate – the two main characteristics being assessed by various test methods [1-8].

The Scotch tape test method (ASTM D3359-02 [1]) has been widely used to evaluate the adhesion strength of the printed image to a substrate. In this method, the Scotch permanent tape is applied to the image area with one finger stroke at even pressure. The tape is then removed and assessed for optical density before and after the application. The adhesion strength is determined by calculating the residual ink density on the tape normalized to the original image density.

The Crockmeter test (F1319-94(2005) [2]) has been extensively used to evaluate the cohesion strength. The amount of imaging particles transferred onto the surface of a white cloth by rubbing has been used to characterize the fixing quality in terms of cohesion strength of the image. As an optional procedure, the optical density change before and after rubbing has also been used to judge the cohesion strength or abrasion resistance of the printed image.

Both the tape test and the crockmeter test are relatively easy to use and the results are simple to interpret. The results can also be classified against pass or failure criteria to enable the introduction of the fixing quality control procedures for the printed images. However, there are some intrinsic problems related to the two methods. In the tape test, the force applied by a finger stroke has significant influence on the amount of toner removed by the tape. Different assessors may apply different forces and even the same assessor may apply different forces at different times. The optical density values also depend on the selection of representative spots from the image samples. For samples with uniform solid fill both before and after the tape test; the densitometer provides a reliable optical density reading. However, on many occasions, after the tape test the samples become uneven and patchy. This usually results in the densitometer providing inconsistent optical density readings.

In the crockmeter test, the measurement of the optical density on the cloth or on the test sample after the test has similar problems in getting consistent optical density readings. There is an additional problem for the crockmeter test, where the optical density of the image after the test may be higher than the one before. All these problems make it difficult to correlate the optical density results from tape and crockmeter tests with those from visual observations and, hence, to achieve consistent performance from those devices.

The crease test (ASTM F1351-96(2002) [3]) has also been used in the fix quality assessment of printed images. Tse et. al. [4] applied this method combined with an automated image analysis system [5] to verify their test procedure. A crease was created across a solid fill area of the image on paper by folding the paper with a controlled force. The paper was then unfolded and loose toner particles along the crease line were wiped away with a clean cotton swab. The optical density from the area surrounding the crease line was used for determining the fix quality. Scott et. al. [6] developed a different crease test apparatus for toner adhesion strength evaluation. This instrument creates a fold with a very small radius in the image area of a paper substrate. The fold is repeatedly rolled across the image sample until the desired degree of wear has occurred. The image fragment is peeled from the paper surface as a result of adhesion failure at critical conditions. A scanner based image analysis technique was developed and used to quantify the toner loss.

Hartus [7] developed a modified tape test technique to measure the adhesion force. The Scotch permanent tape was applied to the print and also the mobile part of a friction meter. The meter applied a controlled and repeatable force to the tape. The tape was then pulled from the paper at a defined speed and angle. An image processing technique was employed to assess the peeling residues. Hartus claimed that the modified tape test enabled a direct measurement of the adhesion force.

The Sutherland Rub Tester [8] or variations of it, and the pen-offset test (POT) were used in the printing industry as well. The POT has become more popular and acceptable in the past few years. In this test, the image is placed faced down on another piece of paper, and a ball pen used to write on the back of the image sample. Toner particles from the image are transferred to the blank paper during the pen writing. The assessment on this offset image can characterize the fix quality of the printed image.

The authors believe that the POT is potentially a better and more effective method for fix quality assessment. However, in its current implementation, the force applied to the ball pen is not well controlled, and depends strongly on the individual assessor. In addition, the offset image on paper is evaluated by visual observation only. The consequence of this practice is that the pen-offset test is unreliable and non-quantitative. It is therefore believed to be of little use in both R&D and commercial environments for obtaining reproducible, reliable and quantitative results.

The authors have designed and built a bench type pen-offset apparatus to apply a controlled and consistent force to the ball pen. The pen is driven by a friction drive carriage to draw a straight line on the back of a solid image. The footprint or the offset image left on the reference paper is then analysed by image processing software, which was developed from the publicly available image-processing software, ImageJ [9]. After processing, the optical density and the line width of the offset image are obtained. It has been found that the fix quality results are best represented by introducing a new characteristic number called the pen-offset number (PON). This is defined as a product of optical density (OD) and the line width (in mm), and further multiplied by 100. The application of the pen-offset test apparatus in the authors' laboratory has demonstrated consistent and reproducible results.

Description of Pen-offset Test Technique

Description of the Pen-offset Test Apparatus

A photograph of the pen-offset test apparatus is shown in Figure 1. It consists of a plate for holding the image sample, pen holder, ball pen and weights (metal disks). The pen holder is motor driven by a friction drive carriage along the parallel rods, and a switch that sets the traveling direction of the carriage.

Description of Image Processing Program for Line Image Analysis

The offset line image produced on paper as a result of the pen-offset test can be characterized by its darkness (optical density) and dimensions (line width). It is obvious that the darker and wider the offset line, the lower the fix strength of the image. Visual observation can provide with a quick judgment on the fix quality of a print. However, the subjective and qualitative nature of this evaluation makes it unsuitable for use in rigorous assessment of fix quality. To overcome this drawback, the authors have applied image processing technology for characterization of the offset line mark. ImageJ has been chosen for its flexibility in enabling the user to create customized program modules in addition to providing an extensive range of general purpose image processing functions. ImageJ was developed and placed in public domain by Wayne Rasband, National Institutes of Health, USA. A customized module to process the line image from the pen-offset test has been developed and integrated into ImageJ.

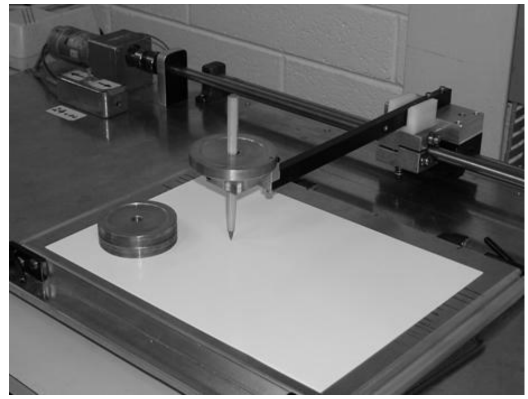

***Figure 1**. Photograph of a pen-offset test apparatus.*

The offset line image on the blank paper from the pen-offset test is first scanned by a professional graphic scanner and saved on a personal computer at a minimal resolution of 1200 dpi. The scanned image is then processed by the image processing software to obtain the optical density, the width of the line image, and, finally, the PON. The PON is believed to represent the amount of toner particles per unit length transferred to the paper from the image sample during the pen-offset test and, therefore, it can be used for characterization of fix quality. The PON typically ranges from 0 to over 50. The smaller the PON; the better the fix quality. For instance, dry powder laser prints can have PON approaching zero, while for a typical offset print, the PON may vary from ~ 0.5 to 2.

Physics of Pen-offset Test

Pressure and Indentation Depth

When a ball pen (Staedtler 430F, tip size 0.8 mm) with a loading force F is placed vertically on paper, a hemispherical indentation is formed on the paper surface as shown schematically in Figure 2. For the stationary pen, the mean pressure, P_s, can be derived from the load, F, and the contact area, πr_s^2:

$$P_s = \frac{F}{\pi r_s^2} \tag{1}$$

As the ball pen moves in the traversing direction, x, the contact area changes from circular (Figure 2a) to semicircular (Figure 2b). In this case, one expects the contact radius, r_m, to increase to a value that in the first approximation would maintain the pressure equal to the stationary case ($r_m \cong \sqrt{2}\ r_s$):

$$P_m = \frac{F}{0.5\pi r_m^2} \tag{2}$$

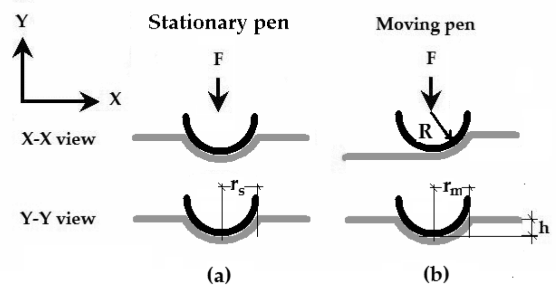

Figure 2*. Indentation on the paper surface for the stationary and moving ball pen. Gray and black lines represent schematically the paper surface and the tip of the pen respectively.*

While using mean pressure values provides reasonable interpretation of the pen-offset test results, the actual pressure profile across the contact area and the stress distribution induced in the ink layer can play a significant role in the accuracy of the density readings for the final ink offset mark on paper. In more complex terms, the interaction between the pen and the paper can be described by the so-called "Hertzian contact" theory, where the pressure distribution in the contact area is elliptical and can be approximated by the following equation [10]:

$$P_S(r) = P_O\sqrt{1-\left(\frac{r}{r_S}\right)^2}$$

$$P_O = \alpha F^{1/3} = 1.5P_m \qquad (3)$$

where P_o is the peak contact pressure in the center of the contact area; r is the radial coordinate in the range from 0 to r_s; F is the loading force; and α is a constant proportional to the Young's modulus and Poisson's ratio of paper, and the indenter's (ball pen) diameter.

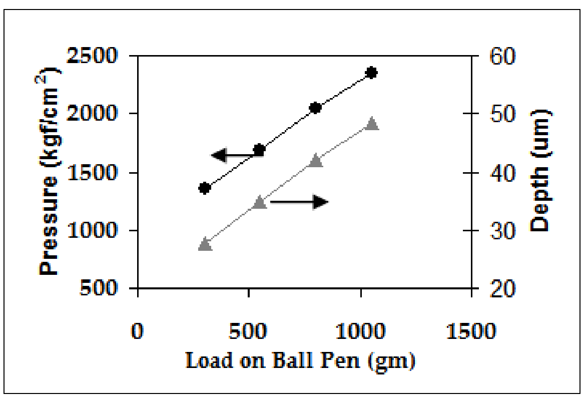

Figure 3*. Calibration results of mean pressure and indentation depth on the paper by a ball pen tip. The result is averaging from two plain papers. The calibration condition is simulated to the pen-offset test. The under layer paper has a thickness of 120 µm and the top layer paper is 100 µm thick.*

To estimate the mean pressure, P_m, and the maximum indentation depth, h, the pen-offset apparatus was used to draw lines on a blank paper at various pen loads. The lines were then scanned to obtain the line width. Assuming the penetration depth is small compared to the ball diameter, both P_m and h can be estimated from the line width using simple geometrical considerations. In Figure 3 the mean pressure and the indentation depth are plotted as a function of the ball pen load. Both parameters show linear increase with load in the applied range. The fact that the mean pressure is a linear and not a cubic root function of load suggests that paper deformation during the pen-offset test is not elastic, probably due to relatively high stresses created in the contact area. In normal handwriting conditions, the force applied to the ball pen is estimated at ~0.3-0.5 kgf, which would result in the pressure on paper over 1000 kgf/cm^2. Under such conditions, the indentation width and depth are around 0.3 mm and 25 µm respectively, translating to extremely high stresses induced in the image layer and at the interface between the image and the substrate during the pen-offset test.

Fragmentation of Image Layer under Pen-Offset Test

The substrate under the ball pen is subjected to both shear and tensile stresses [10-12]. During the pen-offset test, these stresses will propagate from one side of the substrate to the other where the image layer is present. The discussion of these stress fields in the image layer is outside the scope of the current paper.

The finding of Chateauminois' [13] study on a thin polystyrene film may be used to explain the image damage under the pen-offset test. The image layer can be kept intact when the force is less than a critical value, which depends on the fracture toughness of the resin. When the force is increased beyond the critical value, small cracks appear first at the leading edge of the contact, where the image may be able to remain on the substrate if the adhesive force is stronger than the external one. As the force continues to increase, the cracks become larger and may develop into a network. Under these conditions, the image layer fragments, and the adhesive force no longer holds the ink layer to the substrate in many localized areas. This causes the fragmented image elements to be transferred onto adjacent media, such as blank paper in the case of the pen-offset test.

Results and Discussion

Reproducible

Figure 4 shows a scanned image from a typical pen-offset test. The sample was produced using a liquid electrophotographic printing process and fused by a typical hot-roll fuser at a fusing temperature of 140°C. The same sample was repeatedly tested on the pen-offset apparatus to obtain average and standard deviation values.

The line images in Figure 4 were processed by the image processing software. The optical density, line width and pen-offset number are listed in Table 1. In Table 1, the average values from four tests and standard deviation are also reported. The last row of the table comprises relative errors (ratio of the standard deviation to the average value) for key parameters of the pen-offset method. The relative error for the optical density, line width and PON are about 14%, 10% and 3% respectively. The result indicates that the use of the pen-offset number can significantly improve the reproducibility of the pen-offset test.

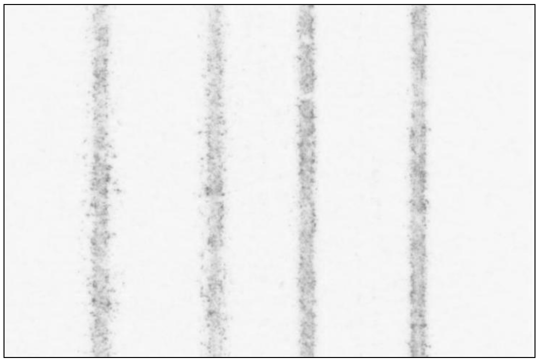

Figure 4. *Example of line images of pen-offset test. The load on the ball pen is 300 gram. This image has shown that the pen-offset test apparatus can deliver repeatable test result.*

Table 1 Image processing result for the line images shown in Figure 4 (The line number is counted from left to right). PON = 100xODxW.

Line No	OD	W(mm)	PON
1	0.30	0.83	24.8
2	0.29	0.85	24.1
3	0.35	0.73	25.2
4	0.38	0.68	25.9
Average	0.33	0.77	25.0
StdDev	0.04	0.08	0.76
StdDev/Ave	14%	10%	3%

To appreciate the accuracy of the pen-offset test method, we performed comparative trials, whereby a group of people used their individual handwriting to replicate the conditions similar to the automated POT. In these trials, each person produced four repeated test lines on the same print sample. A relative error, defined as an average standard deviation of the PON, is depicted in Table 2.

Table 2 Relative error in POT conducted by four independent assessors.

Assessor	1	2	3	4
PON	8.9%	20.7%	38.8%	16.5%

The relative error has a large variance of from 8.9% to 38.8% per individual assessor, and a combined standard deviation of 16%, which is significantly greater than 3% from the pen-offset apparatus.

Application of Pen-offset Test for Assessment of Fixing Quality

Figure 5 shows an example of fix quality as a function of the fusing dwell time (fuser nip width divided by its line speed). The result reveals that the fix quality deteriorated with decreasing the dwell time. The rate of reduction is much more pronounced at short dwell times.

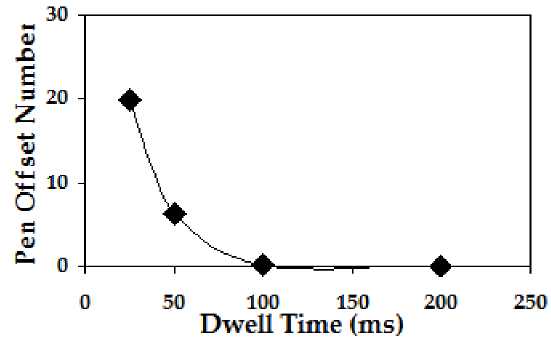

Figure 5. *Fixing quality versus fusing dwell time.*

Figure 5 illustrates that the pen-offset test can be used not only in the fix quality assessment, but also in fusing process optimization work, where it can provide critical information in terms of both the fuser design and toner formulations.

Comparison to tape and crockmeter test

To illustrate the difference in performance between the tape, crockmeter and the pen-offset tests, ten different liquid toner samples with a wide range of properties were selected. The images produced with these toners at constant printing conditions were fused at various temperatures. The criteria for passing these tests were set as follows: $\geq 95\%$ of adhesion strength for the tape test; optical density of ≤ 0.1 for the crockmeter test; and PON number of ≤ 0.5 for the pen-offset test. Figure 6 depicts the results of these trials.

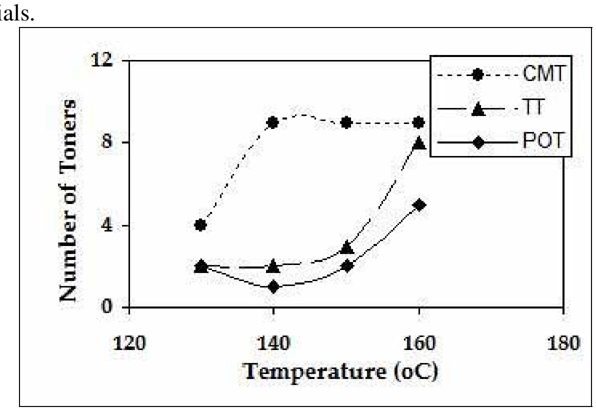

Figure 6. *Comparison of the POT (300g load), tape test (TT) and crockmeter test (CMT) at various fusing temperatures. Total number of toners is 10. Criteria for passing the test were: ≤0.5 for the pen-offset test, ≥95% adhesion strength for the tape test, and optical density of ≤0.1 on the cloth for the crockmeter test. The tape test and crockmeter test were completed according ASTM standard.*

Figure 6 shows that 9 out of 10 toners passed the crockmeter test at the temperature of 140°C or higher. The tape test appears to be tougher for the toners to pass than the crockmeter test at temperatures above 140°C, and the pen-offset test leading the ranking of the group for the resistance of the toner layer to offsetting.

Conclusion

The pen-offset test method has been improved by testing the printed images on a pen-offset test apparatus with a well controlled force and by analyzing the offset line image using the customized image processing software. The quantitative results from the pen-offset apparatus proved to be reproducible and reliable. The pen-offset test method can be widely applied in the toner formulation work and also optimization of the fuser design.

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References

[1] ASTM D3359-02 "Standard Test Methods for Measuring Adhesion by Tape Test", ASTM International, 10-Aug-2002.

[2] F1319-94(2005) "Standard Test Method for Determination of Abrasion and Smudge Resistance of Images Produced from Business Copy Products (Crockmeter Method)".

[3] ASTM F1351-96(2002) "Standard Practice for Determination of the Effect of Hard Creasing Paper on Images Produced by Business Imaging Systems".

[4] Ming-Kai Tse, Francis Y. Wong, and David J. Forrest, A Fusing Apparatus for Toner Development and Quality Control. (IS&T's NIP13, Seattle, Washington, 1997) pg.310.

[5] Quality Engineering Associates, Inc., IAS-1000 Automated Image Analysis System.

[6] C. Tim Scott, Roland Gleisner, Jeanne Dahlke-Bauman, Method for Evaluating Toner Adhesion on Copier Paper (TAPPI Recycling Symposium, 2000) pg.241.

[7] Hartus, T., Adhesion of Electrophotographic Toner on Paper, Graphic Arts in Finland 30(2001)3, pg.14.

[8] ASTM D 5264-98 "Standard Practice for Abrasion Resistance of Printed Materials by the Sutherland Rub Tester".

[9] Wayne Rasband, National Institute of Health, USA.

[10] Hamilton, G., Explicit Expressions for the Stresses beneath a Sliding, Spherical Indenter (Proceedings of the Institution of Mechanical Engineers, **197C**, 53, 1983).

[11] A. C. Fischer-Cripps, The Hertzian contact surface, J. of Materials Science 34 (1999) 129-137.

[12] A. Franco Jr., S. G. Roberts, Surface Mechanical Analyses by Hertzian Indentation, Cerâmica 50 (2004) 94-108.

[13] A. Chateauminois, M.C. Baietto-Dubourg, C. Gauthier, R. Schirrer, In Situ Analysis of the Fragmentation of Polystyrene Films within Sliding Contacts, Tribology International 38 (2005) 931–942.

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Dr Charlie MAO received B.Eng and M.Eng degrees in China in the early 1980s, and a Ph.D. in Australia in 1995. After working as a university lecturer in the area of mining technology, and as a research scientist in soil science, he is now a senior research physicist at Research Laboratories of Australia. Since joining RLA, he has been investigating the mechanisms of image development and process optimisation, and quality analysis of image and image fixing since he joined RLA in 1996. His theoretical and experimental work has contributed to the steady advance of novel liquid electrophotographic technologies.

Alex Ozerov received his Master's degree in Physics from Nizhny Novgorod University, Russia, in 1983. He has over 20 years of experience in research and development of novel technologies in a wide range of applications from microelectronics and material science to radar systems and printing. He joined Research Laboratories of Australia in 1994 and has been working there as a principal technologist in the area of liquid electrophotographic processes. At present, he manages High Viscosity Toner Division at RLA.